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CONSTRAINTS ON VARIABILITY OF BRIGHTNESS AND SURFACE MAGNETISM ON TIME SCALES OF DECADES TO CENTURIES IN THE SUN AND SUN-LIKE STARS: A SOURCE OF POTENTIAL TERRESTRIAL CLIMATE VARIABILITY

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Constraints on variability of brightness and surface magnetism on time scales of decades to centuries in the sun and sun-like stars: A source of potential terrestrial climate variability
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The following summarizes the most important results of our research:

• Conciliation of solar and stellar photometric variability. Previous research by us and colleagues (Lockwood et al. 1992; Radick et al. 1998) suggested that the Sun might at present be showing unusually low photometric variability compared to other sun-like stars. Those early results would question the suitability of the technique of using sun-like stars as proxies for solar irradiance change on time scales of decades to centuries. However, our results indicate the contrary: the Sun's observed short-term (seasonal) and long-term (year-to-year) brightness variations closely agree with observed brightness variations in stars of similar mass and age. These results were presented at the March 2000 workshop held in Tucson for investigators of this program. A manuscript is being prepared to submit for publication.

• We have demonstrated an inverse correlation between the global temperature of the terrestrial lower troposphere, inferred from the NASA Microwave Sounding Unit (MSU) radiometers, and the total area of the Sun covered by coronal holes from January 1979 to present (up to May 2000). Variable fluxes of either solar charged particles or cosmic rays, or both, may influence the terrestrial tropospheric temperature. The geographical pattern of the correlation is consistent with our interpretation of an extra-terrestrial charged-particle forcing. A paper summarizing our results appeared in the March 8, 2000 issue of *New Astronomy*.

• Possible climate mechanism amplifying the impact of solar ultraviolet irradiance variations. The key points of our proposed climate hypersensitivity mechanism are: (1) The Sun is more variable in the UV than in the visible. However, the increased UV irradiance is mainly absorbed in the lower stratosphere/upper troposphere rather than at the surface. (2) Absorption in the stratosphere raises the temperature moderately around the vicinity of the tropopause, and tends to stabilize the atmosphere against vertical convective/diffusive transport, thus decreasing the flux of heat and moisture carried upward from surface. (3) The decrease in the upward convection of heat and moisture tends to raise the surface temperature because a drier upper atmosphere becomes less cloudy, which in turn allows more solar radiation to reach the Earth's surface. A paper summarizing our results appeared in the May 25, 2000 issue of *Annales Geophysicae*.

• Natural variability in an ocean-atmosphere climate model. We use a 14-region, 6-layer, global thermo-hydrodynamic ocean-atmosphere model to study natural climate variability. All the numerical experiments were performed with no change in the prescribed external boundary conditions (except for the seasonal cycle of the Sun's tilt angle). Therefore, the observed inter-annual variability is of an internal kind. The model results are helpful toward the understanding of the role of nonlinearity in climate change.

We have demonstrated a range of possible climate behaviours using our newly-developed ocean-atmosphere model. These include climate configurations with no inter-annual variability, with multi-year periodicities, with continuous chaos, or with chaotically

occuring transitions between two discrete sub-states. These possible modes of climate behaviour are all possible for the real climate, as well as the model.

We have shown that small temporary climate influences can trigger shifts both in the mean climate, and among these different types of behaviour. Such shifts are not only theoretically plausible, as shown here and elsewhere; they are omnipresent in the climate record on time scales from several years to the age of the Earth. This has two apparently opposite implications for the possibility of anthropogenic global warming. First, any warming which might occur as a result of man's influence would be only a fraction of the small-to-large unpredictable natural changes and changes which result from other external causes. On the other hand, small temporary influences such as man's influence do have the potential of causing large permanent shifts in mean climate and interannual variability.

A paper summarizing our results appeared, as an invited paper for celebration of the 25th founding anniversary of the Malaysian Institute of Physics, in *Journal of Physics Malaysia*, 19, 157, (2000).

Other progress includes:

New lamp calibration for Ca II flux records of sunlike stars

In the last year we further improved the method of our lamp calibration and standard-star normalization, which are critical for maintaining the long-term precision of the records. V. Cristina Cristian, a Harvard undergraduate student, helped develop and implement the new analytical process that has yielded an improved precision of the records. As a result, we have unprecedented ability to detect and information on small- amplitude surface magnetic variability in sun-like stars.

New analysis tool for periodicity studies (the modified gapped wavelet)

We developed, with colleague P. Frick (Perm, Russia) a new technique to analyze periodicities and their time-frequency variation in the stellar records, and have published our results on the analysis of four sun-like stars. This new mathematical tool shall be applied for an objective quantification of decade-long magnetic and photometric changes in a larger sample of sun-like stars.

Review of impact of increased atmospheric CO_2 on climate and vegetation

A review of the scientific literature shows a markedly increased rate of plant growth but no clear, deleterious climatic impacts from increased atmospheric CO_2 to-date. We pointed out six main categories of climate processes that would requires further research. We stressed concerns on the use of unvalidated climate models in making future projections of unknown (!) climate forcing scenarios. We finalized our review by discussing observational requirements for a hope of attributing the climatic effects of increasing atmospheric CO_2.

A paper summarizing our results appeared in the October 1999 issue of *Climate Research.*

Modeling climatic effects of anthropogenic CO_2 emissions: Unknowns and uncertainties

A likelihood of disastrous global environmental consequences has been surmised as a result of projected increases in anthropogenic greenhouse gas emissions. These estimates

are based on computer climate modeling, a branch of science still in its infancy despite recent, substantial strides in knowledge. Because the expected anthropogenic climate forcings are relatively small compared to other background and forcing factors (internal and external), the credibility of the modeled global and regional responses rests on the validity of the models. We focus on this important question of climate model validation.

Specifically, we review common deficiencies in general circulation model calculations of atmospheric temperature, surface temperature, precipitation and their spatial and temporal variability. These deficiencies arise from complex problems associated with parameterization of multiply-interacting climate components, forcings and feedbacks, involving especially clouds and oceans.

We also review examples of expected climatic impacts from anthropogenic CO_2 forcing. Given the host of uncertainties and unknowns in the difficult but important task of climate modeling, the unique attribution of observed current climate change to increased atmospheric CO_2 concentration, including the relatively well-observed latest 20 years, is not possible. We further conclude that the incautious use of GCMs to make future climate projections from incomplete or unknown forcing scenarios is antithetical to the intrinsically heuristic value of models. Such uncritical application of climate models has led to the commonly-held but erroneous impression that modeling has proven or substantiated the hypothesis that CO_2 added to the air has caused or will cause significant global warming.

An assessment of the positive skills of GCMs and their use in suggesting a discernible human influence on global climate can be found in the joint World Meteorological Organisation and United Nations Environmental Programme's Intergovernmental Panel on Climate Change, IPCC, reports (1990, 1995, 2001). Our review highlights only the enormous scientific difficulties facing the calculation of climatic effects of added atmospheric CO_2 in a GCM. The purpose of such a limited review of the deficiencies of climate model physics and the use of GCMs is to illuminate areas for improvement. Our review does not disprove a significant anthropogenic influence on global climate.

A paper summarizing our results will appear in a 2001 or 2002 issue of *Climate Research.*

Publications and Presentations

(1) Lifetime of Surface Features and Stellar Rotation: A Wavelet Time-Frequency Approach, W. Soon, P. Frick and S. Baliunas, 1999, *Astrophysical Journal*, 510, L135-L138.

(2) Environmental effects of increased atmospheric carbon dioxide, Willie Soon, Sallie Baliunas, Arthur B. Robinson, Zachary W. Robinson, 1999, *Climate Research*, 13, 149-164.

(3) Natural variability in an ocean-atmosphere climate model, E. Posmentier, W. Soon and S. Baliunas, 2000, *Journal of Fizik (Physics) Malaysia*, 19, 157-164.

(4) Variations of Solar Coronal Hole Area and Terrestrial Lower Tropospheric Air Temperature From 1979 to Mid-1998 W. Soon, S. Baliunas, E. Posmentier, P. Okeke, 2000, *New Astronomy*, 563-579.

(5) Climate Hypersensitivity to Solar Forcing? W. Soon, E. Posmentier, S. Baliunas, 2000, *Annales Geophysicae*, 18, 583-588.

(6) Photometric variations in sun-like stars, G. W. Henry, S. M. Henry, S. L. Baliunas and R. A. Donahue, 2000, poster presented at the Tucson workshop for grant investigators, March 2000.

(7) The sun also warms, S. Baliunas and W. Soon, 2000, *State of the Climate Report 2000*, pub. New Hope Environmental Service, 20.

(8) The sun's energy and climate change: "A grand absurdity"? Sallie Baliunas, Willie Soon, 2000. **Energia**, vol. 11 (no. 3), 4.

(9) Carbon dioxide and global climate change, S. Baliunas and W. Soon, 2000, in *Proceedings of the 53rd Annual Meeting of the Southern Weed Science Society*, (ed. D. B. Reynolds), lxx-lxxix.

(10) Calculating the climatic impacts of increased CO_2: The issue of model validation, W. Soon, S. Baliunas, S. B. Idso, K. Ya. Kondratyev, and E. S. Posmentier, 2000, in *Proceeding of 1st Solar and Space Weather Euroconference: The Solar Cycle and Terrestrial Climate*, (ESA Publication, SP-463: ed. M. Vázquez), 243-254.

(11) The impact of anthropogenic CO_2 emission on climate: Unresolved Problems" (in Russian), W. Soon, S. Baliunas, K. S. Demirchan, S. B. Idso, K. Ya. Kondratyev, and E. S. Posmentier, 2001, *Proceedings of the Russian Geographical Society*, 133, 1.

(12) Modeling climatic effects of anthropogenic CO_2 emissions: Unknowns and uncertainties, Willie Soon, Sallie Baliunas, K. S. Demirchan, Sherwood B. Idso, Kirill Ya. Kondratyev, and Eric S. Posmentier, 2001, *Climate Research*, in press

(13) How the Sun also warms: Solar Variability and Climate Change, W. Soon and S. Baliunas, 2001, in *Global Climate Change: Science and Policy* conference publication by The James A. Baker III Institute for Public Policy at Rice University, in press.

NB: Over 20 invited scientific colloquia were presented on the topic but are not listed separately.